A Spatial Tool for Analysis of the Effects of Grazing Land Management Scenarios on Carbon Sequestration in Australian Rangelands

M. J. Hill[a], R. Braaten[a] and G. M. McKeon[b]

[a] *Bureau of Rural Sciences and CRC for Greenhouse Accounting, Edmund Barton Building, Barton, Canberra, ACT (michael.hill@brs.gov.au)*

[b] *Queensland Department of Natural Resources and Mines and CRC for Greenhouse Accounting, Indooroopilly, Qld*

Abstract: Management of grazing lands is to be included in greenhouse accounting and emission reduction targets. This paper describes a spatial system for scenario analysis of the effect of changes in grazing management on rangeland carbon balances. The system is based on identification of alternative biophysical carbon states and incorporates the effects of management changes and socio-economic and cultural barriers to changes. Development of the system involved: adaptation of an existing computer interface in the ArcInfo GIS; selection of rangeland vegetation zones; selection of a carbon state and transition structure; a knowledge-mining workshop with rangeland experts; and population of tables of relative carbon stocks and drivers of change. The analytical process incorporates grazing pressure, fire, woody weeds, woody plant introduction and clearing. Climate, social and economic factors are also considered. The interaction between sustainable carrying capacity and actual stocking rate is used to examine the sensitivity of model outputs to climate variability, changes in stocking rate and the relative carbon indices and area proportions supplied by experts. It is important to establish a complete and ecologically sound representation of carbon state dynamics and climate/vegetation interactions to ensure that scenario analysis is valid and useful.

Keywords: Carbon sequestration; Rangelands; Spatial tool; State and transition model

1. INTRODUCTION

Management of grazing lands has been included in greenhouse gas accounting and emission reduction options [Sampson and Scholes, 2000]. This paper describes implementation and some sensitivity analysis for a spatial system for analysis of the impact of changes in management on rangeland carbon balances. The system is based on a conceptual model developed by Stafford-Smith et al. [1997] that describes a process for assessment of biophysical, socio-economic and cultural factors affecting changes in rangeland management that may result in increased carbon storage. It was implemented using a combination of expert knowledge, state and transition models for rangeland carbon, spatial data of varying detail and quality using a GIS interface.

2. RANGE-ASSESS

The RANGE-ASSESS scenario analysis framework is based on ASSESS (A System for Selecting Suitable Sites) a user-friendly interface to the full functionality of the Grid module for manipulating raster data in the ArcInfo GIS [Veitch and Bowyer, 1996]. Range-ASSESS allows users to simulate changing the management of different rangeland zones, and models the effects of these changes on the vegetation states of these areas. The carbon stores in vegetation and soil are then adjusted according to the modelled vegetation states. It is designed to enable scenarios to be examined in a workshop situation, to facilitate rapid analysis of changes in carbon stocks arising from different management practices.

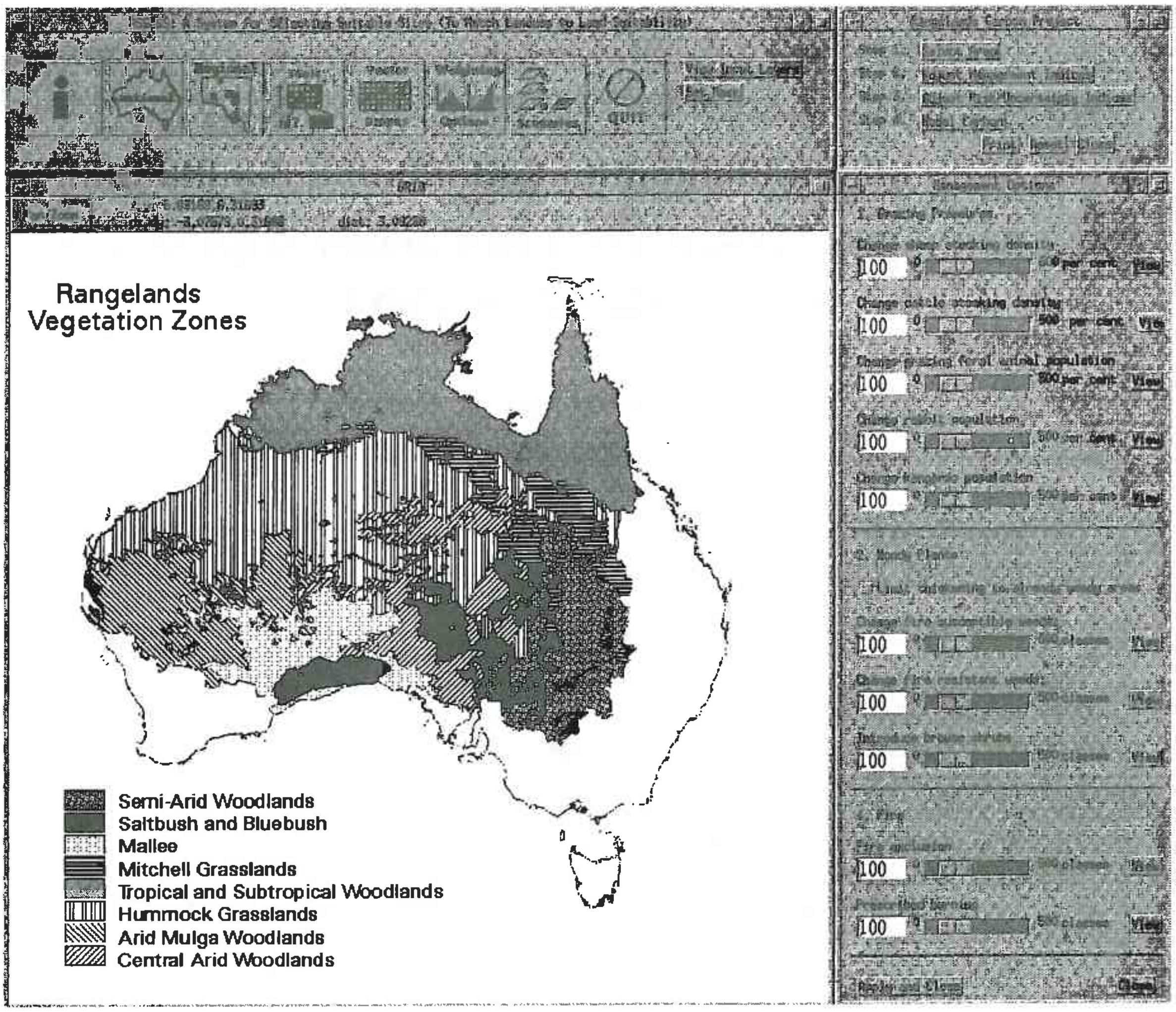

Figure 1. Range-ASSESS interface showing the rangelands regionalisation into eight zones based on Harrington et al. [1984] and the menu for applying management changes.

The Range-ASSESS system was developed as follows:

- A regional sub-division of the rangelands, recognisable to experts, was constructed based on the zones defined in Harrington et al. [1984].
- A simplified conceptual state and transition model [Westoby et al. 1989] was devised where vegetation states are defined by significant change in biomass or soil carbon.
- The ASSESS interface was built incorporating slider bars and indices for changing factors governing carbon storage (Figure 1).
- Relatively undisturbed biomass and soil carbon is described by a continental 1 km data set produced from simulations with the VAST model [Barrett, 2001].
- Spatial data layers such as feral animal distributions; stocking density; woody weed distribution; climate and fire scar maps were modified and incorporated into the framework.
- A workshop was conducted with a panel of rangeland experts with region-specific knowledge of the condition of the rangelands in order to populate tables with indices describing relative carbon states and list the major drivers of change.
- Climate risk was summarised using relationships between the Southern Oscillation Index (SOI) and the Interdecadal Pacific Oscillation (IPO) and rangeland production and degradation which affect mainly eastern Australia. The analysis identifies 6 year-types associated with the values of the IPO and SOI (Table 3) which result in decreases or increases in growth potential of rangelands, and frequency of droughts. We use the frequency of occurrence of year types and the percentage change in grassland growth to

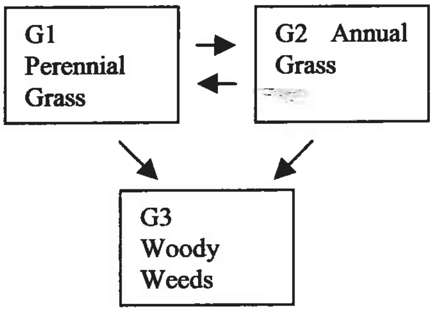

Figure 2. State and transition model for the Mitchell Grasslands.

Table 1. States and relative carbon indices for the Mitchell Grasslands.

State	Type	Area NT-WA	Area Qld	Soil C Index	Bio-mass C Index
G1	Perennial grassland	0.8	0.8	1.0	1.0
G2	Annual grassland	0.2	0.15	1.0	0.2
G3	Annual grassland with woody invasion (*Acacia nilotica*)	0	0.05	0.8	10.0

create a multiplier for carbon sequestration over 50 years (Table 3).

- Social and economic constraints to adoption of management changes are represented by simple indices between zero and one.

Further development is planned and the version described here is essentially a prototype within which not all management factors (e.g., fire) are operational. A full description is provided in Hill et al. [2001].

2.1 State and Transition Structure

The simplified state and transition models used in Range-ASSESS are illustrated by the model for the Mitchell Grasslands (Figure 2). The area proportions and carbon indices for the states are shown in Table 1. Transition between states G1 and G2 are controlled by grazing pressure and rainfall (Table 2). The transition to state G3 requires seed introduction by animals and absence of fire (Table 2). Once woody weeds are established, mechanical intervention or severe, human-induced burning is required for recovery to the other states. State and transition models such as this are present for each rangeland zone, and in some cases a number of subclasses within the zone.

Table 2. Transitions and drivers of change between Mitchell Grassland states.

Transitions	Drivers
G1 to G2	Heavy grazing and drought
G2 to G1	Reduced grazing and rain
G2 to G3	Seed introduction with grazing and no fire
G3 to G2	No occurrence
G1 to G3	Seed introduction with grazing and no fire
G3 to G1	No occurrence

Table 3. Classification of years by phase of SOI and IPO used to develop future climate scenario impacts on carbon sequestration.

Year	Type	Number of years	Rain % Dev-iation	Growth % Dev-iation
SOI <= -4 IPO < 0	1	16	-18	-18
SOI >= 4 IPO < 0	2	17	33	44
SOI <= -4 IPO >= 0	3	17	-14	-26
SOI >= 4 IPO >= 0	4	11	5	11
SOI > -4 & < 4 IPO < 0	5	17	12	11
SOI > -4 & < 4 IPO >=0	6	30	-9	-11

3. GRAZING PRESSURE AND CARRYING CAPACITY

In constructing Range-ASSESS, we sought in the first instance to address the issue of the impact of grazing on rangeland vegetation and carbon sequestration. Combined grazing pressure from feral grazing animals was generated from distribution maps for individual feral grazers and information on animal numbers and dry sheep equivalent conversion factors from many sources

Stocking rates with livestock were represented by allocating 1997 agricultural census data to freehold and lease hold land tenure areas (Guppy, unpublished data; Figure 3). Carrying capacity was estimated using simple annual rainfall relationships [Wilson et al., 1984] for winter- and summer-

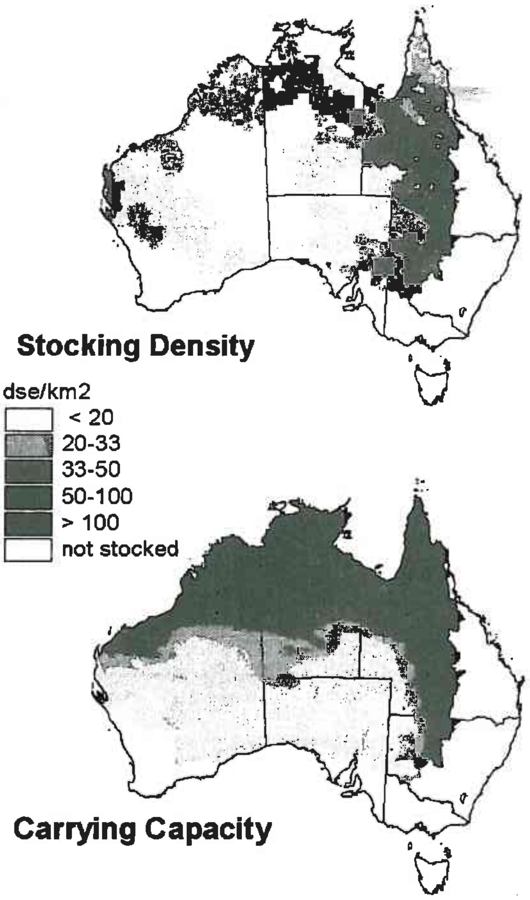

Figure 3. Layers describing stocking density and carrying capacity used in analysis of management change scenarios.

dominant areas (Figure 3). Within Range-ASSESS, the stocking density and carrying capacity layers are simplified to 5 class layers as shown in Figure 3, in order to facilitate rapid processing.

4. SENSITIVITY AND RESPONSE ANALYSIS

All scenarios were run over a period of 50 years. Grazing pressure and climate were the only drivers used. For transitions which depended on additional drivers (e.g., fire), the requirements were assumed to be satisfied. A change of state dependent on grazing pressure was assumed to occur if grazing pressure was greater than carrying capacity. A change of state dependent on drought was assumed to have occurred if drought frequency was greater than one per decade.

Climate - The proportion of climate year types was varied from equal proportions of only the three driest year types (1,3,6) to equal proportions of only the wettest year types (2,4,5). Each pass consisted of a 5% change in the proportions; real climate sequences are non-random but for the purposes of this simulation real year frequencies were not used (Table 4).

Table 4. Iterative changes in frequency of climate year types used in simulations.

Pass	Year type (%)					
	1	2	3	4	5	6
1	33.3	0	33.3	0	0	33.3
2	31.7	1.7	31.7	1.7	1.7	31.7
3	30.0	3.3	30.0	3.3	3.3	30.0
...						
21	0	33.3	0	33.3	33.3	0

Use of prescribed burning for wildfire control – For an average, dry and wet climate prescribed burning was applied to no areas; to crown land only; or to all land in the tropical and subtropical woodland only.

Livestock stocking density - Stocking rate was varied from 0 to 200% of present value in increments of 20% for three climatic scenarios: average, based on historical occurrence of the year types; dry, based on equal proportions of only the three driest year types (1,3,6); and wet, based on equal proportions of only the three wettest year types (2,4,5).

Relative carbon index - Analyses were conducted for the Mitchell grasslands and arid mulga. The carbon indices for soil and biomass for states 2 and 3 were varied from 50% to 200% of their original values in increments of 20%, while all other indices were held constant.

Proportions of area in each starting state – Analyses were conducted for the Mitchell grasslands and arid mulga. The proportions of the vegetation zone area starting in each of the three possible states were varied from 0 to 1 in intervals of 0.1. While one state was being varied, the other two were adjusted proportionately to sum to 1.0.

5. RESULTS AND DISCUSSION

Climate simulations predict significant declines in carbon stocks in all zones under prolonged dry conditions at current stocking rates (Figure 4) but if assumptions are accepted, these changes may be cyclical and not controllable. An initial increase in woody understorey with increasing dryness results in a small positive change in carbon which may be an artefact. The stocking rate simulations predicted that carbon storage could decline significantly at

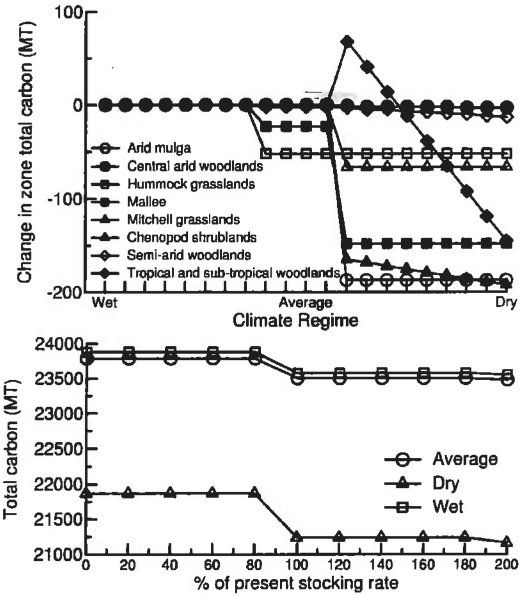

Figure 4. Sensitivity of simulated carbon storage; by zone, to climate variability and in total to livestock stocking rates.

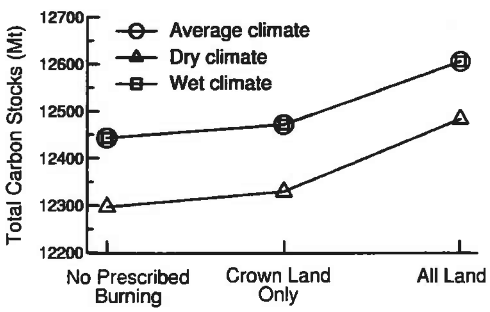

Figure 5. Effect of prescribed burning to reduce wildfires on carbon stocks in the tropical and subtropical woodlands for three climate regimes.

stocking rates above 80 - 100% of the present levels (Figure 4). Simulated carbon storage under a dry climate is substantially lower than for average or wet conditions. The state transition is set to occur immediately if grazing pressure exceeds carrying capacity; an unrealistically rapid effect. However, the results probably fairly represent current gradual degradation and the vulnerability of Australia's rangelands to future carbon losses under current stocking rates and dry conditions.

The tropical woodlands have four possible states: State 1. - Open woodland with perennial grassland; State 2. - Open woodland with annual grassland; State 3. - Woodland with dense woody understory and perennial/annual grasses; State 4. - Thinned woodland and woody understorey. With no prescribed burning (Figure 5), a significant proportion of state 1 goes to state 4 due to high fire frequency. With prescribed burns, this transition is halted resulting in an increased carbon store.

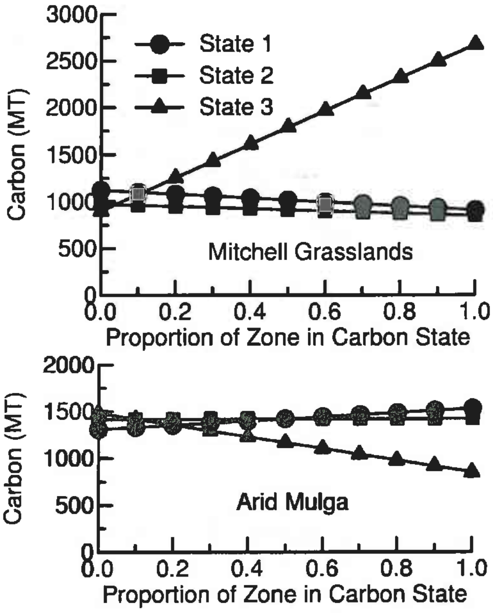

Figure 6. Sensitivity of simulated carbon storage to proportion of zone in carbon states for Mitchell Grassland and Arid Mulga.

Under the no intervention scenario, a large proportion of state 2 goes to state 1 because low grazing pressure and average dryness allows regeneration of the perennial grasses. However, under a dry climate, this transition is halted resulting in a lower carbon store.

Figure 6 shows the effect on carbon storage of varying the proportions of a zone in each carbon state. The responses depend on the relative carbon content of each state. For the Mitchell grasslands, changes in the proportion of the area in state1,perennial grassland, and state 2, annual grassland, result in small changes in total carbon, as the two states contain similar amounts of carbon. Increases in state 3, woody weed infestation, result in a significant increase in carbon stocks since biomass carbon is high in state 3.

For the arid mulga zone, while changes in states 1 (mulga with low shrubs and grasses) and 2 (mulga with no understorey) have relatively small effects on carbon storage, an increase in the area of state 3 (sheet eroded) results in a large decrease. These results suggest we require accurate estimates of the initial proportion of the vegetation zone in states which involve large changes in carbon stock, and accurate estimates of the magnitude and likelihood of increases or decreases in the area of this state.

The effect of changes in relative carbon index on overall carbon storage (Figure 7) depends on the importance of the biomass or soil component of a given state in determining the overall carbon store

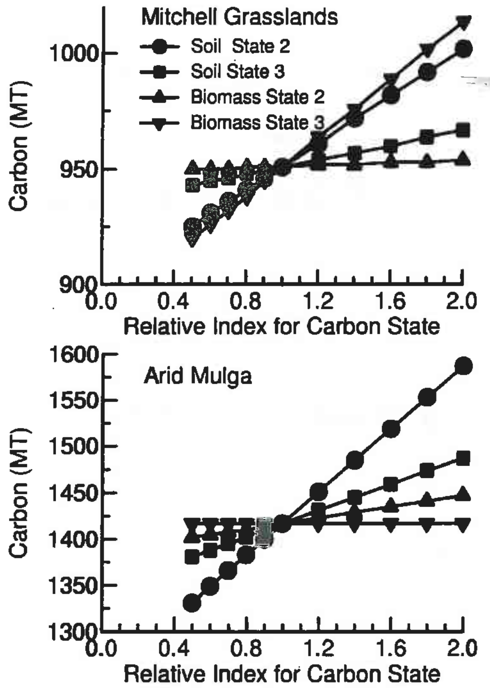

Figure 7. Sensitivity of simulated carbon storage to relative carbon index for two rangelands zones; Mitchell Grasslands and the Arid Mulga.

for that zone. For example, for the Mitchell grasslands, varying the soil carbon index for state 2 (annual grassland) has a large effect on overall carbon as soil carbon makes up the majority of carbon stores in that zone. For the arid mulga, the large effect of the soil carbon index for state 2, mulga with no understorey, relates to the importance of soil carbon in that state and zone Varying the biomass carbon coefficient for state 3, sheet eroded, has no effect as all biomass is lost in that state. For the extreme scenarios where the carbon coefficients are doubled or halved, a substantial effect on overall carbon is modelled. However, for reasonable changes of ± 10% or ± 30% of the original estimates, the changes in overall carbon are < 2% and <5% respectively. These changes are slight and suggest that the model should respond in a robust fashion to errors in expert estimation of the relative carbon indices.

6. CONCLUSIONS

The balance between grazing pressure and carrying capacity and the influence of climate variability determine the outcomes of scenario simulations with Range-ASSESS. The relative carbon indices and proportions of zones in different states assigned by experts proved to be relatively robust. However, the key to capturing realistic future scenarios lies with a robust and quantitative representation of:

- spatial variation in rangeland vegetation and condition;
- response of each vegetation system to the grazing and climate stresses; and
- representation of the temporal patterns of degradation and recovery.

We are seeking to improve our representation of these factors through new satellite data and simulation modelling.

7. REFERENCES

Barrett, D. J., VAST Model NPP dataset, Australia, 2001.*

Harrington, G. N., A. D. Wilson, and M. D. Young (eds.), *Management of Australia's Rangelands* (CSIRO, Australia) 354 pp. , 1984.

Hill, M. J., R. Braaten, and 11 others, Range-ASSESS: A spatial framework for analysis of potential carbon sequestration in Australian rangelands, Technical paper No. 1, CRC for Greenhouse Accounting, Canberra, 2001.

Sampson, R. N. and R. J. Scholes, Additional human-induced activities – Article 3.4, In, *Land Use, Land-Use Change, and Forestry*, R. T. Watson, I. R. Noble, B. Bolin, N. H. Ravindranath, D. J. Verardo and D. J. Dokken (eds.), A Special Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, pp 181-282, 2000.

Stafford-Smith, M., D. Ojima, and J. Carter, Integrated approaches to assessing sequestration opportunities for carbon in rangelands, In, *Combating Global Climate Change by Combating Land Degradation – Proceedings of a Workshop, Nairobi, Kenya, 4-8 September 1995*, V. R. Squires, E. P. Glenn and A. T. Ayoub (eds.), United Nations Environment Programme, Nairobi, pp. 305 – 326, 1997.

Veitch S. M. and J. K. Bowyer, ASSESS: A GIS-based system for selecting suitable sites, In: *Raster Imagery in Geographic Information Systems*, S. Morain and S. Lopez Baros (eds.), Onword Press, Santa Fe, pp. 182-191, 1996.

Westoby, M., B. H. Walker, and I. Noy-Meir, Opportunistic management for rangelands not at equilibrium, *Journal of Range Management*, 42: 266-274, 1989.

Wilson, A. D. and G. D. Harrington, Grazing ecology and animal production. In, *Management of Australia's Rangelands*, G. N. Harrington, A. D. Wilson, and M. D. Young (eds.), CSIRO, Australia, pp. 63-78, 1984.

*http://daac.ornl.gov/npq/non_guides/vast_des.html